

# USING BIOMASS TO IMPROVE SITE QUALITY AND CARBON SEQUESTRATION

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## ABSTRACT

The future demands on forest lands are a concern because of reduced productivity, especially on inherently poor sites, sites with long-depleted soils, or those soils that bear repeated, intensive short rotations. Forests are also an important carbon sink and, when well managed, can make even more significant contributions to sequestration and to reduction of greenhouse gases. This paper looks at the use of forest biomass as a carbon sink and as a source of nutrients for enhancing or restoring site productivity. It is hypothesised that wood incorporated into the soil will store carbon for an unknown length of time, and an example analysis using logging residues is presented. A field study was also conducted to evaluate the use of mulching and tilling as site preparation tools for incorporating biomass into the soil.

**Keywords:** carbon, nutrients, site preparation, biomass

## INTRODUCTION

Much of the United States', and particularly the South's, forest soils are in degraded condition due to past land-use practices or are inherently carbon and nutrient poor. Enhancing and restoring degraded and poor soils can lead to increased productivity and carbon sequestration. An effective means of increasing and stabilising soil organic matter is through the application of organic soil amendments, and forest biomass in the form of logging residues is usually a readily available source. Coupled with the need for site preparation treatments that include stump and slash clearing or displacement from the planting row, logging slash mulching (comminution into small particles) and incorporation into the soil has appeal as a means to accomplish all these objectives.

This paper explores the use of mulching/tilling to prepare harvested sites for planting, improve and restore short- and long-term site productivity, and sequester carbon. Our hypotheses are:

- comminution of slash and stumps provides good site preparation,

- incorporation of woody biomass and humus improves nutrient retention and carbon pools,
- incorporation slows wood decomposition, reduces CO<sub>2</sub> flux, and lengthens carbon storage (short-term benefit),
- incorporation makes carbon more readily available for nutrient cycling and captures more carbon through soil biotic processes that lead to reduced CO<sub>2</sub> flux, and
- incorporation improves soil physical properties that enhance both short- and long-term productivity, i.e., providing for carbon storage in both vigorously growing above-ground biomass and below-ground root mass that can be used to perpetuate the carbon storage and nutrient retention cycle.

The first section of this paper addresses the use of woody biomass for enhancing soil carbon storage capacity. A hypothetical example is given for increases in carbon pools using residues from conventional logging, and when a significant

portion of the merchantable volume is diverted to improving soil. Secondly, the paper presents the methodology of a field study that was only recently

installed to explore using incorporation of woody biomass to enhance soil carbon and nutrient storage capacity.

## LITERATURE REVIEW

Much is known about nutrient cycling and mineralisation in forest soils, and the important role of the carbon cycle in soil productivity. The above-ground processes of decomposition of biomass, humification, the release of emissions, and the return of organics to the soil are fairly well understood. Less is known about below-ground carbon processes, and the role of organic amendments in nutrient and carbon cycling. Very little research has addressed decomposition of wood incorporated into the soil.

Nutrient turnover rates are generally more relevant to forest productivity than total soil carbon is (Cole & Rapp 1981; Edmonds & Hsiang 1987; Binkley & Hart 1989). Increasing organic matter in soil is an important key to long-term productivity. Besides regulating forest productivity, organic matter dynamics are critical to carbon sequestration. Although the consequences of carbon sequestering in forest soils are not well understood, evidence suggests that there may be a negative feedback between organic carbon levels and carbon allocation to plant root systems that limit carbon storage in the soil (Ruark & Blake 1991). Significant increases in the recalcitrant soil organic matter fractions may suggest the potential for carbon sequestration. Since this fraction has been linked to the soil's physical properties (Elliot 1986; Beare *et al.* 1994), fluxes in the size or chemical identity of this fraction may result in significant long-term changes in the soil.

Accurate knowledge of carbon dynamics at the landscape and stand scale is needed to predict and manage forests. Presently, models that evaluate the potential effects of climate change on forest sustainability include a limited amount of information on carbon dynamics. Improving our understanding of carbon processes relative to common soil variables, such as texture, will contribute to the accuracy of such models.

Several models describing soil organic matter dynamics have been presented (Van Veen *et al.* 1985; Jenkinson 1990; Verberne *et al.* 1990; Hassink & Whitmore 1997). A common theme among these models has been the importance of clay, especially in warmer climates (McDaniel & Munn 1985; Amelung *et al.* 1997). However, the capacity of a soil to preserve organic matter is

limited by the soil's protective capacity (Hassink 1995; Hassink & Whitmore 1997) which is the maximum amount of carbon that can be associated with the clay and silt fractions. Once this capacity is reached then no additional soil organic matter can be stored (Hassink 1995). Hassink & Whitmore (1997) recognised that a significant portion of the soil protective capacity cannot be accounted for by clay content. They estimated this portion to be between one-third and one-half of the total protection. It is possible that part of this is correlated to the soil micropore density. Organic matter incorporation into micropores and microaggregates is a recognised mode of physical protection for the soil organic matter, and forest management strategies that alter soil micropore and microaggregate density may significantly affect the ability of the soil to sequester carbon.

Incorporating the mulched material by tilling the soil can enhance soil structure and loosen the soil, permitting improved air and water infiltration. However, the soil will be exposed and initial oxidation of soil organic matter may be more rapid than on sites where the mulch is on the surface. Another consideration is that many mulched plant materials have a high C:N ratio and will tie up large amounts of nitrogen during decomposition, thus reducing nutrient availability for the new vegetation, while the woody biomass can provide few direct nutrients except for essential micronutrients. Incorporating the biomass into the soil simultaneously incorporates the carbon and nutrients into the soil, minimising the loss of nitrogen, in particular, to the atmosphere. The increased carbon capital on the site will improve soil physical properties and enhance the nutrient retention capacity of the site over the longer term.

The use of woody biomass as a soil amendment could be expected to have an impact on carbon mineralisation and sequestration. Carbon mineralisation and CO<sub>2</sub> evolution accompany elevations in pH and have been attributed to changes in soil microbial populations. The carbon dynamics may be further influenced by the altered chemistry of soil organic matter and specific clay types at elevated pH levels. At elevated soil pH levels, the association between soil organic matter and clays will be primarily through cationic bridges. At low

soil pH, protons can displace the cations and change the soil organic matter – clay interaction from a cationic bridge to a hydrogen bond. A consequence of this activity may be that the soil organic matter will not be as strongly associated with the clay, thus

making the soil organic matter susceptible to decomposition. Further investigations are necessary to quantify carbon mineralisation and sequestration reactions in soil amended with woody biomass to determine the extent of its influence and utility.

### AN EXAMPLE OF BELOW-GROUND CARBON STORAGE

A conceptual model of the hypothesised system is shown in Fig. 1. The two standard pathways for standing biomass are: (1) for harvested tree and stand components to be removed from the site and enter a product stream, e.g., biofuels, paper, or solid wood products, and (2) for litter accumulated over the rotation and logging residue to be left on the soil surface after harvest. In this conceptual model, leaving the litter and logging residue on the soil surface would lead to essentially the same growth rate for the next rotation, all other things being equal. Another possibility is shown by the shorter pathway associated with incorporating the litter and logging residue into the soil which, by improving the physical properties and the nutrient retention and cycling properties of the soil, would increase the productivity of the site and lead to increased growth rates. Additional options presented in Fig. 1 are: (1) the incorporation of some portion of the material that would normally be harvested and enter the product stream, and (2) the incorporation of all of the standing biomass. This might be an appropriate option on those sites where the existing standing biomass has no product value but, if incorporated into the soil, may have significant value for increasing the carbon and nutrient capital (and long-term productivity) of the site.

The analysis of the potential carbon available to return to the site by comminution and incorporation of the residual biomass was done using two

hypothetical loblolly pine (*Pinus taeda* L.) stands grown in the south-eastern United States. One stand represented a poor site (Site Index 25 = 15 m) and one a good site (Site Index 25 = 21 m). Stand yields for determining the amount of carbon in the stand were taken from Clutter *et al.* (1984). The methods for determining the amount of carbon in the stand were taken from Birdsey (1992). Three harvest options were used in the analysis: (1) removing all the merchantable volume, (2) removing all the merchantable volume to a 5 cm top, and (3) removing all the merchantable volume to a 5 cm top in stems greater than 15 cm diameter at breast height (dbh). In the analysis the top 30 cm of soil was taken as directly affected by the mulching and tilling. Residual biomass and logging slash were assumed to be comminuted and incorporated into the soil.

The carbon removed from the site under the various options is shown in Table 1. The impact of the various options on the amount of carbon in the soil after incorporation is given in Table 2. The base amount of carbon in the top 30 cm of soil was approximately 79 000 kg/ha (Brady 1974). The results showed that potentially significant gains in the amount of soil carbon can be attained by incorporating biomass into the soil. Significant unknowns are the fate, forms, and amount of carbon that could be added to the carbon capital of a site or stored as slowing decomposing organics over the long term.

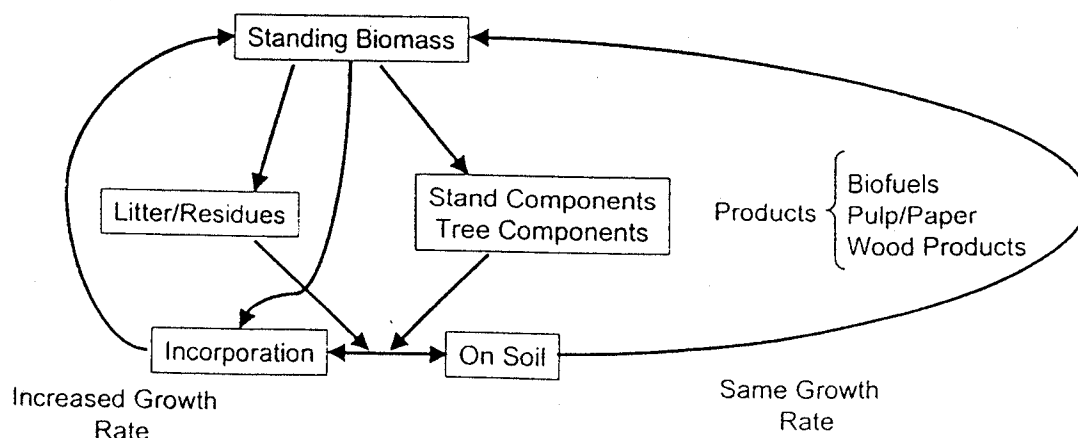


Fig. 1. Conceptual model of stand components and potential growth rates following harvest and incorporation of biomass. Based on flow chart presented by Schlamadinger & Marland (1996).

Table 1. Carbon removed from the site and returned to the soil for a range of harvest options for loblolly pine (*Pinus taeda* L.).

Harvest option	Site Index (base age 25 years)			
	15 m		21 m	
	C removed (kg/ha)	C returned (kg/ha)	C removed (kg/ha)	C returned (kg/ha)
Total merch. vol.	44 535	40 534 (trees) 4 454 (forest floor) 44 988	85 737	78 012 (trees) 8 574 (forest floor) 86 595
Merch. vol. (to 5 cm top)	44 121	40 948 (trees) 4 454 (forest floor) 45 402	85 192	78 566 (trees) 8 574 (forest floor) 87 140
Merch. vol. (to 5 cm top, stems > 30 cm)	36 623	48 446 (trees) 4 454 (forest floor) 52 900	78 438	85 320 (trees) 8 574 (forest floor) 93 894

Table 2. Potential soil carbon in top 30 cm of soil from incorporation of different levels of stand biomass. The table entries include the base carbon available in the soil, an average of approximately 79 353 kg/ha (2.08%) in the top 30 cm of soil.

Harvest option	Site Index (base age 25 years)			
	15 m		21 m	
	(kg/ha)	Total soil C (%)	(kg/ha)	Total soil C (%)
Total merch. vol.	124 341	3.27	131 997	3.47
Merch. vol. (to 5 cm top)	124 755	3.28	166 493	4.38
Merch. vol. (to 5 cm top, stems > 15 cm)	132 253	3.48	173 247	4.60

### FIELD STUDY

A preliminary study was installed in the fall of 1997 to compare mulching/tilling with conventional site preparation techniques. The study was a joint effort with Weyerhaeuser Company, Virginia Tech University, and Rayco Manufacturing Company. Goals of the study were to compare the effects of shearing/bedding and mulching/tilling on soil physical and chemical properties.

The sites are located on Lower Coastal Plain soils in eastern North Carolina. The stands were typical loblolly pine plantations that had been clearcut and were to be replanted with the same species. Two soils were selected, one highly organic and one highly mineral, in order to isolate the effect of adding woody organics to the soil. Also, mulching the slash and stumps as a treatment was compared to mulching and tilling into the soil as another treatment. Finally, a comparison was made between mulching strips (similar to the conventional operation) and broadcast mulching.

A Rayco\* Model FM726 Forestry Mower/Mulcher was used to install the study. The machine has a 2.4-m horizontal rotating drum with 36 attached swing hammers that: (1) mulches logging slash, stumps, and humus layer, (2) tills the soil approximately 20 cm deep, and (3) mixes the woody biomass into the soil. The machine was powered by a 205-kW engine and was mounted on tracks. The conventional operation included one pass of a dozer with a KG V-blade to shear stumps and roll logging debris to the sides to clear the strip for bedding. Another dozer was used on the second pass to apply fertiliser and to bed with a disk bedding plow.

### Treatments

The treatments differed by soil type. On the organic site, the treatments were:

- Control: no mulching, no V-shearing, no bedding, no fertiliser, no weed control

\* The use of brands and trade names is for the convenience of the readers and does not imply an endorsement by the USDA Forest Service, Weyerhaeuser Company, or Virginia Tech.

- Conventional: V-shearing, bedding, fertiliser, weed control
- Strip mulch: bedding, fertiliser, weed control
- Strip mulch/till: bedding, fertiliser, weed control

On the mineral site, the treatments were:

- Control: no V-shearing, no bedding, no fertiliser, no weed control
- Conventional: V-shearing, bedding, fertiliser, weed control
- Strip mulch: bedding, fertiliser, weed control
- Strip mulch/till: bedding, fertiliser, weed control
- Broadcast mulch: bedding, fertiliser, weed control
- Broadcast mulch: no bedding, fertiliser, weed control

The plots were 40 × 40 m, 0.16 ha. The area was blocked based on logging traffic and micro-elevation and had four blocks per treatment in close proximity to ensure uniformity of residual slash, stump size and distribution, and soil.

### Measurements

An effort was made to quantify the levels of above-ground logging slash and the size and distribution of stumps. This information was also used to help locate the plots for uniformity.

Soil cores were taken to quantify the soil horizons. Water wells were installed to measure water tables and for access to water chemistry samples. Volumetric soil samples were taken before and after the installation of the treatments. Later, tree growth measurements will be made to assess plot productivity.

Water chemical samples were taken from the wells for dissolved O, C, and P. Lysimeters were used to understand the soil water flux. These samples were analysed for dissolved organic carbon,  $\text{NH}_4\text{-N}$ ,  $\text{NO}_3\text{-N}$ , total nitrogen, total phosphorus, pH, and conductivity.

Soil samples were collected near each well from each soil horizon to a depth of 50 cm and analysed for organic matter, texture, pH, nitrogen, and phosphorus. Additionally one standard 2-inch soil core was collected from each horizon to evaluate bulk density, porosity, hydraulic conductivity, and air permeability.

Soil moisture was evaluated using a time domain reflectometer (TDR) near each well point at depths

of 15, 30, and 60 cm. Sampling rods were permanently installed at each soil depth and these stations were measured monthly in conjunction with the wells and lysimeters. A rusty rod was inserted near each well so that average reducing conditions could be evaluated. At the same locations and depths as the TDR measurements, soil temperature and soil oxygen levels were measured.

Soil  $\text{CO}_2$  evolution was measured monthly at five locations within each measurement plot. One sampling point was centrally placed within the measurement plot and the other four sampling points were placed near the four corners of the measurement plot. Bulk soil  $\text{CO}_2$  evolution includes root activity and microbial activity. All  $\text{CO}_2$  measurements were done in the field using a portable  $\text{CO}_2$  chamber system.

At the  $\text{CO}_2$  sampling points, soil cores were collected from the upper 15 cm of the mineral soil. The soil cores will be collected on a half-year basis and will be used to quantify the labile and recalcitrant organic matter fractions. Portions of the soil cores were extracted to remove the labile organic matter fraction using the method of Sanchez & Ruark (1995). The remaining portions of the soil cores will be analyzed by particle size and density fractionation by the method of Meijboom *et al.* (1995). Soil aggregate stability measurements were also made from the soil samples.

### Outcomes

An assessment of the soil, water, vegetation, and gases will provide a basis for constructing the carbon balance of the site, and for a better understanding of treatment effects on soil quality. Quantifying the labile and recalcitrant organic pools will give an estimate of carbon sequestered in the soil. Chemical characterisation of these pools will provide insight on their inherent resistance to microbial decomposition. Carbon sequestered in vegetation will be determined from the biomass measurements. Monitoring the soil water movement and composition will give estimates of carbon and nutrient loss from the plots.  $\text{CO}_2$  measurements will give estimates of carbon loss to the atmosphere. This information along with soil moisture, temperature, and other data will help parameterise future carbon and nutrient dynamics models.

The study will also provide information on the benefits derived from ameliorating soil physical characteristics. Measurements of bulk density, soil porosity, hydraulic conductivity, and air

permeability will aid in determining the physical factors affecting site productivity and CO<sub>2</sub> efflux.

The site quality and carbon budget information will be valuable for understanding the relationships as well as establishing the effectiveness of the

treatments. This understanding will become more important as land managers are given more responsibility in managing both productivity and carbon, which translates into managing biomass effectively.

### FUTURE QUESTIONS

Mulching and tilling may be an effective way to regenerate sites, but may also be cost prohibitive unless value is given to increasing site productivity and sequestering carbon. Certainly, there are significant questions as to how well the activity does perform these functions. Our hypotheses are only hypotheses that still have to be proved or disproved. Our preliminary tests will not be able to answer all, if any, of the major questions on below-ground decomposition and the gas fluxes. Much work is still needed to determine if carbon can be stored short- or long-term and/or if incorporation enhances mineralisation and the capture of carbon in the biotic processes. Other studies are already being planned to better address these issues, particularly deep tilling and decomposition rates of various forms of woody biomass. We plan to evaluate the

incorporation of the woody biomass at depths greater than 45 cm.

The analysis, although based on many assumptions, shows the potential to increase soil carbon through the use of residual biomass. Increases in the nutrient pools and resulting site productivity may also be derived from above-ground biomass. If biomass can be used for such values as site enhancements and carbon storage, the question becomes the "appropriate" use of logging residues, or any component of the stand or tree that has multiple values—and not purely monetary. In the long run, which is best: to reduce the use of fossil fuels with renewable energy, or to offset emissions by sequestering more carbon in a biological system? We need to know.

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